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A REPORT ON THE 6TH RAPID EXCAVATION AND TUNNELLING CONFERENCE, 12-16TH JUNE 1983, CHICAGO, ILLINOIS

T.R.C. Aston
Cape Breton Coal Research Laboratory

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A REPORT ON THE 6TH RAPID EXCAVATION AND TUNNELLING CONFERENCE, 12-16TH JUNE 1983, CHICAGO, ILLINOIS

by

T.R.C. Aston*

SUMMARY

This report reviews those conference sessions attended by a member of the CBCRL along with relevant questions, answers and comments. The application and/or relevance of these sessions to both the Donkin-Morien project and the Sydney Coalfield in general is also given.

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*Research Scientist, Cape Breton Coal Research Laboratory, CRL, CANMET, Energy, Mines and Resources Canada, Sydney.

RAPPORT SUR LA 6th RAPID EXCAVATION AND TUNNELING CONFERENCE, CHICAGO (ILLINOIS); 12-16 JUIN 1983

par

T.R.C. Aston*

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Le présent rapport décrit les séances auxquelles a assisté un membre du LRCCB. Il inclut les questions, les réponses et les commentaires. On indique aussi dans quelle mesure ces séances concernent le projet Donkin-Morien et le gisement de charbon de Sidney en général.

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*Chercheur, Laboratoire de recherche sur le charbon de Cap-Breton, LRC, CANMET, Énergie, Mines et Ressources Canada, Sydney.

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INTRODUCTION

In the summer of 1983, a 7.6 m diameter Tunnel Boring Machine (TBM), manufactured by Lovat of Toronto is scheduled for delivery to the Donkin-Morien Development Project in Cape Breton, Nova Scotia. Work to monitor the geotechnical behaviour of the resulting bored tunnel is being undertaken by Golder Associates in the form of a U.P. (DSS. 26 SQ.23440-2-9159) entitled 'Measurement and Analysis of Rock Deformation and Support System Response in the Drill and Blast, and Bored Access Drivages at the Donkin-Morien Project'.

At the 6th Rapid Excavation and Tunnelling Conference (RETC), 12-16th June 1983 in Chicago it was considered essential for a member of CBCRL to attend and:

1) Report on the proceedings.
2) Meet and discuss informally with conference participants 'state of the art' research on TBM's and other rapid excavation techniques.
3) Answer questions related to the geotechnical work proposed for the TBM at the Donkin-Morien project.

In addition to interest concerning the TBM, numerous discussions also developed concerning the work being undertaken by CBCRL in the Sydney Coalfield.

This report outlines details of the conference sessions attended along with relevant questions, answers and comments. The application and/or relevance of these sessions to either the Donkin-Morien project or the Sydney Coalfield is also considered.

The Sixth Rapid Excavation and Tunnelling Conference

A breakdown of the conference sessions is given in Appendix A. However, with a conference of this size where sessions are simultaneously time tabled, it is not always possible to attend all those papers considered relevant to the ongoing work of the Cape Breton Coal Research Laboratory (CBCRL).

MONDAY 13TH JUNE AM - GROUND CONTROL FOR SUBSURFACE MINING EXCAVATIONS

Paper 1 - Rock Mechanics Applications in Underground Coal Mine Ground Control

This paper was not available when the proceedings went to press, although contact with the author after the session resulted in a copy subsequently being sent to CBCRL. Essentially, the paper describes the use of simple convergence measurements taken in room and pillar workings for predicting areas of instability. In conjunction with the convergence measurements a borehole periscope was also used in those areas already identified as being potentially unstable. Subsequent discussions revealed that problems had been experienced with the periscope, regarding design, construction and usage, although it should be noted that the instrument was made prior to optic fibre technology. Bed separations within the overlying strata were monitored using the periscope, although no details were given regarding the data collection methodology. A report on the use of the periscope is believed to have been prepared by the Occidental Research Corporation, and might be available to outside research organizations. One of the major problems encountered during this work appeared to be the method used to drill the observation boreholes. Cuttings and mud tended to 'cake' the borehole sides and make visual inspection of cracks and fissures impossible, without prior cleaning. The attachment of a camera to the periscope might provide a continuous and permanent record of the borehole.

In addition to the use of a borehole periscope, the paper also mentions the use of chemical agents for the stabilization of mine roofs. Essentially the technique involves the injection of a polyurethane foam into roof strata surrounding an unstable area.

The paper was considered particularly important since Golder Associates are assembling a borehole periscope for use on the Donkin-Morien project. Also CBCRL is interested in the use of chemical methods for stabilizing soft mine floors. Finally, with further research and development the foam injection method may offer a partial solution to the roof instability problems currently being experienced at Prince mine.

Paper 2 - Ground Control Aspects of Longwall Coal Mining

The paper outlines details of the Conoco Research Division ground control investigations around longwall workings. Unfortunately, the paper gives only generalized results and no technical details concerning either the instrumentation and/or data collection techniques.

Paper 3 - A Rock Mass Classification Scheme for the Planning of Caving Mine Drift Support

The paper presents a 'unified' rock mass classification system for use in underground mines employing caving techniques. The system was designed such that it could be integrated into the design and planning stage of the project, in order to assess the eventual support requirements of the mine. The immediate question raised is, could such a system be derived for use in Coal Measures strata or developed for use in room and pillar and/or longwall coal mining? One of the main problems highlighted was that the system was derived 'empirically' from a limited number of sites and had not been fully tested against either new conditions or mines.

A comparison appears to exist between the application of this system to new areas and the recent DSS Contract OSQ82-00113 - A Rock Classification System for Application in Underground Coal Mining which attempted to produce a unified rock classification system for use in all the coal mining areas of Canada.

Paper 4 - Selection of Heading Machines for Excavation in Coal Measures Rocks - Application of Rock Classification Approach

Not available when the proceedings went to press and not presented at the conference.

Paper 5 - Subsidence Damage Criteria

Since paper 4 was not available for presentation, an additional paper was inserted into the program. This was entitled 'Subsidence Damage Criteria' by E. Cording from the University of Illinois. The start point of the work involved examing subsidence over tunnels in soft ground (Trans A, IMM Vol. 92, January 1983, pp A28-A61, 'Tunnelling' 82: Report of Discussion).

Angular movements and lateral strains were measured and related to the amount of damage experienced by buildings. A 'semi-empirical' predictive model was then developed. This was then extrapolated to the damage experienced by buildings over old room and pillar workings.

This technique could be used for a back analysis of room and pillar workings and building damage encountered in the Sydney Coalfield. An analysis of the available data might be usefully integrated into the long term subsidence research programme which has been proposed for the Sydney Coalfield.

MONDAY 13TH JUNE PM - CURRENT STATE OF RESEARCH FOR THE MECHANICAL EXCAVATION OF ROCK

Paper 1 - Hard Rock Tunnel Boring: A Summary of Recent Developments

The paper concentrates on an examination of recent developments in the boring of hard rock using TBM's. Various performance parameters are examined:

1) Effect of load per cutter path
2) Effect of spacing between cutter paths
3) Effect of cutter dullness (i.e. cutter edge width)
4) Effect of cutterhead RPM
5) Effect of rock strength on machine torque

It would be useful to compare similar parameters collected from field trials undertaken in 'soft' rather than 'hard' rock.

Paper 2 - CSM-USBM Rotary Cutting Machine: Research Capabilities and Trials for Improving the Performance of Tunnel, Shaft and Raise Boring Machines

The paper describes the specifications and capabilities of a 6 ft. (1.83 m) diameter laboratory rotary cutting machine (laboratory scale TBM), designed and awarded to the CSM under a USBM contract. The test machine is used to initiate research and development programmes aimed at improving the design and operation of mechanical tunnel, raise and shaft boring equipment. A list of the parameters which can be monitored is given in Appendix B.

A combined research project could be initiated in conjunction with the USBM and CSM to investigate the performance of tunnelling machines in soft rocks, such as Coal Measures strata.

Paper 3 - Laboratory Disc Cutting Studies in Medium and Hard Rocks

The paper describes the research activities carried out by the Transport and Road Research Laboratory, U.K. into the mechanical cutting characteristics of rocks with compressive strengths of up to 340 MPa using disc cutters.

Paper 4 - A Unified Rock Classification for Drilling and Boring

The paper presents a rock classification system which can be used to estimate the key parameters for the operating equipment (drilling and boring), such as thrust and speed, or performance such as penetration rate and bit life.

Unfortunately, in the discussion it was mentioned that although an extensive data base was assimilated from the literature, a matching theoretical base also had to be developed. This approach was necessary because the data proved incomplete, scattered and even flawed. Also no consistent format for the data existed and the units were often vague or non-existent. In view of these comments, the value of this work should be considered suspect and any use of the system either kept generalized or interpreted with caution.

TUESDAY 14TH JUNE AM - SOFT GROUND TUNNELLING

Session Comments

In this session four papers were given concerning tunnelling methods in soft ground (unconsolidated deposits). The paper 'An Experience on the Use of Open Shield in Softground Shallow Tunnelling' by R.M. Ocampo-Franco was neither available at the time the proceedings went to press nor presented at the conference.

Points of interest noted during the session were:
Paper 1 - 'Recent Advancements in Slurry Shield Tunnelling' by Y. Kawarabata highlighted the increasing use of laser guidance systems for controlling the inclination and alignment of tunnelling machines. Paper 2 - 'New Developments in Bentonite Shield Tunnelling' by C. Becker mentioned that if the machine became stuck or required major underground repairs, when being used in water bearing sediments, it was first necessary to freeze the ground surrounding the tunnelling machine.

TUESDAY 14TH JUNE PM - RECENT EUROPEAN EXPERIENCE

Paper 1 - Mechanical Heading of the Walgau - Headrace Tunnel in Austria

The paper presents the drivage of the Walgau tunnel, Austria, length 21 km and diameter 6.25 m as a case history for the use of TBM's in hard rock with difficult ground conditions (i.e. potential mud and water inflows associated with faulting). In addition to highlighting the advantages of using a TBM for the rapid excavation of long tunnels, the paper also confirms the need for extensive geological and geotechnical investigations prior to the commencement of work.

Paper 2 - NATM Usage in Difficult Ground Conditions

NATM - New Austrian Tunnelling Method. The paper shows the application of the NATM in soil rather than rock tunnels. Three case histories are given which highlight the technical and economical advantages of the different auxiliary construction methods used in connection with the NATM.

Paper 3 - Modern Tunnelling Technology in Deep German Coal Mines Under Difficult Ground Conditions

Initially, the paper highlighted the drivage rate advantages of TBM's over drill and blast methods:

Drill and Blast - Average advance rate 3 m/day, peak 13 m/day.

TBM - Average advance rate 13 m/day, peak 40 m/day.

In German coalfields, TBM's are used at depths in excess of 1000 m for developing roadways through Coal Measures strata. The hazards associated with the use of TBM's in these roadways are examined as well as the major causes. Precautionary and remedial measures are given as well as four case histories. This paper was considered particularly important because of the new Lovat 7.6 m diameter TBM being delivered to the Donkin-Morien project later this summer.

Paper 4 - Hydraulically Supported Faces in Coarse and Loose Soils

The paper describes a case history where the use of the Hydroshield method allowed the confirmation of design criteria for front support and surface subsidence under extremely mixed face conditions (soils). The Hydrojet cutting system - excavation by immerged slurry jets - is also described.

WEDNESDAY 15TH JUNE AM - TUNNEL BORING PROJECTS FOR MINING AND OTHER NON-CIVIL APPLICATIONS

Paper 1 - Incline/Decline Boring with Tunnel Boring Machines

The paper considers the difference between the design requirements for incline/decline and horizontal TBM's. In general few modifications are required for a gradient of less than 20%. Usually the thrust requirement for the cutters is unaffected, although the muck haulage, gripper, hydraulics, electrics, lubrication, personnel and parts transfer systems, as well as the equipment maintainability all require detailed examination and modification where necessary.

Paper 2 - Specific Problems Connected with the Application of Full-Face Tunnelling Machines in German Coal Mines

Six full-face tunnelling machines are currently operating in West German coal mines. The paper describes a variety of problems encountered during the use of these machines. In addition to describing the problems, the methods of overcoming them and where appropriate the modifications made to the TBM's are also given. Unfortunately few specific technical details are included in the text. The list of problems discussed are: Modifications to the Cutter Head, Drivages in Squeezing Ground, Maintenance work on Cutter Head, Methane Gas Emission and the Influence of Ground Support Work on the Advance Rate.

Paper 3 - Tunnel Boring in South African Gold Mines

The paper contains considerable practical experience concerning the behaviour of TBM's and in particular their cutter heads in very strong, highly abrasive quartzite rock (Strength 100-300 MPa (14-43000 psi)). An examination is also made of the problems encountered, the solutions devised, the results obtained and perhaps most importantly the lessons learned by the project team.

Paper 4 - Mine Development with Heavy Roadheaders

Heavy duty roadheading machines, exceeding 35 tons in weight, although extensively used in Europe have only seen limited use in North America. The paper describes a case history involving the use of a Paurat E-169, 45 ton roadheader to drive a 2682 m long, 14 degree slope in Kentucky. The results indicate that given favorable conditions, heavy duty roadheading machines are an effective alternative to both conventional drivage methods and full-face tunnelling machines.

WEDNESDAY 15TH JUNE PM - DRILLING, BLASTING AND SUPPORT TECHNIQUES FOR RAPIDLY ADVANCING TUNNELS

Session Comments

In this session four papers were given concerning the use of drill and blast techniques for driving tunnels in both soil and rock. The papers concentrated on the positive aspects of the technique, such as high advance rates, often in difficult ground conditions. A range of available equipment and the variety of support techniques were also discussed. However, the session appeared to emphasize two main points:

1) The need to employ a highly developed logistics system in order to achieve rapid advance rates.
2) Drill and blast techniques only appear economically viable in either tunnels of relatively short length or areas technically and logistically remote.

Throughout the session and for that matter the conference there appeared to be an underlying opinion that drill and blast techniques would eventually become obsolete for all but the most specialized projects. This trend would be brought about by the further technological development, use and increased cost benefit of both roadheaders and full-face tunnelling machines.

CONCLUSION

The conference brought together a variety of people from many diverse sections of the tunnelling industry in an atmosphere conducive to both formal technical presentations and informal discussions. Insight and a 'state of the art' knowledge of the industry were also gained and numerous questions answered regarding the type of projects and work being undertaken by the CBCRL. Finally, in addition to the exchange of technical information contact was also made with 14 mining equipment manufacturer's, six consultancy firms and the U.S. Bureau of Mines. A copy of the conference proceedings (2 volumes) is available at the Cape Breton Coal Research Laboratory.

APPENDIX A

TECHNICAL PROGRAM

MONDAY, JUNE 13, AM

DIFFICULT GROUND

9:00 AM — **Adams**

Chairman: H. L. Blohm, Bechtel Civil & Minerals, Inc., San Francisco, CA

Exploratory Shafts and Underground Test Facility for the Waste Isolation Pilot Plant (WIPP): *P. K. Frobenius, B. R. Chytrowski, D. L. Roberts,* and *C. L. Wu*, Bechtel National, San Francisco, CA

The US Dept. of Energy (DOE) is constructing the Waste Isolation Pilot Plant (WIPP) to demonstrate the feasibility of disposing of defense related nuclear waste in the bedded salt deposits of the Delaware Basin near Carlsbad, NM. The WIPP facility, consisting of two exploratory shafts, shaft stations, access drifts and experimental storage rooms, is under construction. Direct observation and analysis of the behavior of the representative openings is anticipated to confirm the adequacy of the underground design and allow full scale construction of the first US underground nuclear waste storage facility to proceed.

Methodology for Geotechnical Evaluation of an Underground Powerhouse in Weak Rock: *J. L. Rosenblad, R. E. Ranken,* and *D. M. Cregger*, Stone & Webster Engineering Co., Boston, MA

The construction of a large span, high-walled underground opening in a low strength shale rock is unprecedented. The feasibility of constructing a pumped storage project with several tunnels and a large underground powerhouse in low strength shale is cited largely on the feasibility of building stable openings large enough to accommodate the required equipment. Because of the lack of experience with large openings in shale, the decision was made to excavate a test adit and test chamber and conduct a multi-faceted geotechnical evaluation program designed to yield pertinent in situ data. Factors considered in the shape, size, orientation, and location of the test chamber were: (1) similarity to the anticipated powerhouse chamber, (2) nature of the most important data to be obtained, (3) feasibility of construction, and (4) economics.

Basin Electric Lake Tap—Case History Including Contract Conditions: *J. J. Brady*, Brady Underground, Knoxville, TN

The paper will discuss the completion of this difficult Lake Tap in North Dakota. The Target Estimate form of contract used for such work will be explored.

Rock Engineering Design and Construction of High Head Pressure Tunnels for the Drakensberg Scheme: *L. P. Gonano*, Golder Associates, Bellevue, WA and *J. C. Sharp*, Jersey, England

The Drakensberg Pumped Storage Scheme in South Africa with an operating head of 500m is located in sedimentary rocks containing relatively weak argillaceous strata. The paper describes the unprecedented design and construction problems encountered with the high pressure tunnels and the investigation techniques and construction control applied to overcome them.

FINANCING AND RISK

9:00 AM — **Monroe**

Chairman: G. P. Balboni, Perini Corp., Cambridge, MA

The Financing of Mass Transit in the United States: *C. A. Gargano*, Urban Mass Transportation Administration, Washington, DC

The current state of the mass transit industry in America will be examined. How and why this important urban activity shifted from the private sector to the public sector. Who pays for transit, for day to day operating costs and for capital investment? The prospects for transit's future are rather good. Over the past decade major new transit investments have been made in Atlanta, Baltimore, Washington, DC, and Miami, as well as constant re-investment in such cities as New York, Boston, Philadelphia, and Chicago. While the current administration has temporarily halted the initiation of any major rail transit projects using federal funds, localities can use other resources for such projects, these will be explored. Less costly mass transit alternatives are also attracting attention; such as bus operations, which often use imaginative management techniques, such as exclusive lanes on major highways and reserved transit ways in downtown sections.

Financial Risk Management for Underground Construction: *D. B. Ashley*, University of Texas, Austin, TX

Risks in underground construction are often viewed as technical in nature. "running ground," "squeezing ground" and "chimneys" are terms that appear in construction managers' nightmares and occasionally in their underground projects. Financial consequences of these and other project risks are reviewed. Special attention is paid to sources of cost overruns. From this study a structure evolves for setting priorities for risk management actions. these actions can also be tested for impact and potential effectiveness. Finally, case study reviews of six underground projects indicate the "state of the practice" for financial risk management.

Milwaukee Water Pollution Abatement Program—Owner Implementation of Better Contracting Practices Recommendations: *J. H. Meinholz* and *D. G. Wieland*, Milwaukee Metropolitan Sewerage District, Milwaukee, WI, and *J. G. Zack, Jr.*, Ch2M Hill, Inc., Milwaukee, WI

The paper will describe the $1.6 billion Milwaukee Program. Past contracting practices of the Milwaukee Metrophtan Sewerage District are discussed. To minimize costs and claims, the MMSD has implemented some recommendations from *Better Contracting for Underground Construction*. Currently implemented are: full disclosure of subsurface data including interpretations, the deletion of disclaimers relating to subsurface information, use of the federal Differing Site Condition clause, and payment for mobilization. Also considered was the recommendation concerning Wrap Up Insurance. The MMSD shares and allocates certain designated risks through the Contract. A claims handling methodology has been developed and used on this major construction program.

Insuring Property & Casualty Risks Associated with the Construction of the Baltimore Metro: *J. M. Murphy*, Fred S. James Co., Arlington, VA

The Baltimore Subway Project is a 14.5 km (9 mile) heavy-rail rapid transit system under construction in Baltimore, MD sponsored by the Maryland Dept. of Transportation Mass Transit Administration. This system will cost approximately $750,000,000 and is the first phase of a planned intermodal transit system to serve the Baltimore Metropolitan Area. The project commenced on December 1, 1976, and is scheduled to be operational by July 1, 1983. The author—as director of Baltimore Regional Insurance Transit Services, a joint venture of four insurance brokers—designed, implemented and coordinated an insurance and loss control program covering the construction risks involving Workers' Compensation, Public Liability, and Builders Risk Insurance. The discussion will include the process of analyzing the risks associated with the subway project, the techniques of risk transfer and, finally, the management of the construction risks during the building process.

Casualty and Property Concerns for Tunneling Contractor: *C. N. Greene*, Aetna Casualty & Surety Co., Hartford, CT

The paper will discuss a typical casualty and property insurance program for tunneling contractors with an emphasis on broadening features generally available. It will also discuss the loss responsive rating plans and excess limits programs. Coverage to be discussed includes: Workers' Compensation, Comprehensive General Liability (Broad Form Property Damage, Completed Operations, Independent Contractors, Contractural, Incidental Malpractice, Exposure and Collapse, and Underground Hazards); Auto Liability, Auto Physical Damage; Protective—Principle and Railroad; Umbrella; Builder's Risk/Installation Floater; and Contractor's Equipment.

GROUND CONTROL FOR SUBSURFACE MINING EXCAVATIONS

9:00 AM — **Red Lacquer**

Chairmen: Z. T. Bieniawski, The Pennsylvania State University, University Park, PA
H. von Schonfeldt, Occidental Research Corp., Lexington, KY

Rock Mechanics Applications in Underground Coal Mine Ground Control: *B. R. Pothini* and *H. von Schonfeldt*, Occidental Research Corp., Lexington, KY

In underground coal mining many excavated openings have a relatively short projected life span. To ensure safety for men and materials at a minimum cost over the

projected operating life, only pillars for overburden support and roof bolts for support of the openings are used extensively. Mining activity constantly changes the geometry of the mine producing load changes on the structural support members of the openings that often induce unstable deformations which can lead to roof falls or pillar failures. The paper describes how simple deformation measurements can be used to design primary and supplementary roof supports and to predict roof falls and possibly pillar bumps. Specifically, bed separations in the roof measured directly with the help of borescopes and calculated from differential convergence data are used to optimize bolt links or support requirements for chemical stabilization of mine roofs. Roof falls are predicted on the basis of admissible values for cumulative convergence between roof and floor, convergence rate, and the change of the rate of convergence. The pillar extraction operations convergence anomalies detected from contouring identify bump prone pillars, while convergence and pillar dilation determine the yield zone in a pillar to verify pillar softening and de-stressing.

Ground Control Aspects of Longwall Coal Mining: *D. S. Choi* and *D. L. McCain*, Conoco Inc., Ponca City, OK

This paper discusses some aspects of ground control for longwall coal mining, especially those concerning the first major roof break where competent formations are present in the roof strata. An example shows a mathematical model analysis conducted prior to installation of the longwall that was followed up with field measurements. Some results are given. In addition, a predictive method is given for the control of ground movement and control of abutment pressure with the proper use of coal pillars.

A Rock Mass Classification Scheme for the Planning of Caving Mine Drift Support: *F. S. Kendorski* and *R. A. Cummings*, Engineers International, Inc., Westmont, IL; *Z. T. Bieniawski*, The Pennsylvania State University, University Park, PA; and *E. H. Skinner*, US Bureau of Mines, Spokane, WA

This rock mass classification or rating scheme allows mine planners to assess the support requirements of drifts in mines using caving methods. The system was developed based upon studies of case histories and field investigations at several active mines. The Geomechanics (or RMR) System was chosen as a base after detailed examination of the applicability of all presently available rock mass classification schemes. Through a series of modifications to the basic RMR value determined for the rock mass, a sequence of modified RMR values are obtained. These assess the rock mass characteristics and reinforcement, or support, or both, requirements for drifts used for mine service areas (such as shops) away from active caving, initial drift development, and final drift support and buttressing. Final drift buttressing builds upon the initial support for development and, recognizing the strains induced in the containing rock mass, provides the planner with preliminary assessment of the probably heavier support to resist not only the initial excavation strains, but the mining and wholesale rock excavation and drawing deformations. Field checking has demonstrated the applicability of the scheme, the mine planner now has a powerful tool for assessing support requirements for a new or expanding mine by noting readily-obtainable geologic and engineering information.

Selection of Heading Machines for Excavation in Coal Measure Rocks—Application of Rock Classification Approach: *A. K. Ghose*, Indian School of Mines, Dhanbad, India

The increasing application of roadheading machines in the coal industry has prompted the development of an appropriate selection methodology for such machine applications in specific locales. Accurate geological sections and comprehensive rock testing are required for all machine tunneling. Using suitable geotechnical parameters and index tests, sensitive both to *excavability* and *standability* of the strata, a classification scheme has evolved to help evaluate the rock mass vis-a-vis application of a given weight-class of roadheading machine. The classification parameters include point load index, brittleness, abrasiveness, average crack density, and ground water, which with assigned numerical ratings, lead to a quantitative global rating of the rock mass. For each rock mass class, the selection of an appropriate roadheading machine is recommended. The paper illustrates the application of the rock mass rating system and also describes simple index tests for evaluating the classification parameters for brittleness and abrasiveness.

June 16-20, 1985

7th Rapid Excavation and Tunneling Conference

New York, New York

MONDAY, JUNE 13, PM

CASE HISTORIES

2:30 PM — **Adams**

Chairman: P. Kenny, Kenny Construction Co., Wheeling, IL

Metropolitan Boston Transit Authority Red Line Project, Harvard Square to Porter Square Tunnels, Cambridge, Massachusetts: *D. F. Meyer*, Morrison-Knudsen Co., Inc., Boise, ID

In October 1980, the Metropolitan Boston Transit Authority awarded a $47,500,000 CD tunneling contract to a joint venture sponsored by Morrison-Knudsen Co., Inc. Work on this portion of the MBTA's Red Line in Cambridge, MA involved excavation of four shafts, 1.46 km (4800 ft) of rock tunnel, 8 km (2600 ft) of each tunnel and 12 km (400 ft) of mixed face tunnel. Although no shafts were concrete lined under the instant contract, all tunnels were lined to 5.79m (19 ft) I.D. Excavation equipment included both hydraulic and pneumatic tunnel jumbos and two hydraulic excavator shields. Earth stabilization in certain areas of the project was accomplished with a deep ejector system.

Milwaukee's Northeast Side Relief Sewer System: *T. H. Budd* and *D. J. Heinz*, Kenny Construction Co., Wheeling, IL

Milwaukee, famous or infamous for difficult tunneling conditions, was successfully mined by Kenny Construction Co. using a 2.85m (9 ft) diameter Loval TBM. The contract required use of Compressed Air and prescription of ground support. Cooperation between the design and construction teams provided owner savings. In soft ground, progress reached up to 50m (164 ft) in one shift, but was highlighted by achieving mixed face tunneling with the soft ground machine with advance rates up to 23m (76 ft) in one shift.

Construction of Pacific Gas and Electric Company's Kerckhoff-2 Underground Hydro-Electric Project 1980-1983: *E. M. Woodward*, Dillingham Construction Inc., Pleasanton, CA

This paper will present the various methods utilized and results achieved by Auburn Constructors, a joint venture of Dillingham Construction, Inc. & Guy F. Atkinson Co. in construction of this 140 MW underground plant, including use of conventional tunneling methods, used of a 24' TBM for driving of a 6.7 km (22,000 ft) power tunnel, raise boring & slashing of both vertical & inclined shafts, and construction of an 25.9m (85 ft) diameter domed underground powerhouse all located in California's massive Sierra Nevada granite.

Massachusetts Bay Transportation Authority Porter Square Rock Chamber: *D. E. Thompson*, Haley & Aldrich, Inc., Cambridge, MA and *E. S. Plotkin*, MacLean Grove Co., Greenwich, CT

The Porter Square Station trainroom chamber was constructed as part of the Massachusetts Bay Transportation Authority's Red Line Extension in Cambridge, MA during 1980 and 1981. The chamber is 21 m (75 ft) wide, 14 m (45 ft) high and 168 m (550 ft) long, and was excavated in bedrock using drill and blast techniques. Ground support was provided by a combination of rock reinforcement, shotcrete and steel ribs. The paper describes aspects of the design and construction.

THE CURRENT STATE OF RESEARCH FOR THE MECHANICAL EXCAVATION OF ROCK

2:30 PM — **Red Lacquer**

Chairmen: N. G. W. Cook, University of California, Berkeley, CA
E. Worden, Drilco Industrial, Midland, TX

Hard Rock Tunnel Boring: A Summary of Recent Developments: *G. L. Dollinger*, Robbins Machine, Inc., Seattle, WA

The number of tunnels being bored by mechanical means in hard rock is greater today than ever before, and there are indications that the demand for hard rock TBM's will increase in the future. Among the developments that have been investigated are the use of high pressure and low pressure water jets, vibratory cutters, and the development of high thrust capacity cutters. However, because of technical problems, significant breakthroughs in hard rock boring technology are not expected in the near future. Instead, efforts should be concentrated on improving the existing kerf cutting system by developing machines and cutters that are capable of handling the high thrust and RPM's required in hard rock tunneling. The increase in the use of TBM's in hard rock tunneling has also created a need for a better understanding of the dynamics of me-

chanical rock boring. Some mathematical models of TBM performance, of course, exist and are being used by manufacturers today. These models, however, are viewed somewhat skeptically since they have not been widely tested in the field. This is due to the small number of systematic field studies that have been run in the past. The amount of good field performance data has increased dramatically due to the systematic collection of such data during field tests on new equipment. The data, combined with laboratory test results, are beginning to give us a much clearer picture of the dynamics of mechanical rock boring than we have ever had before.

CSM-USBM Rotary Cutting Machine: Research Capabilities and Trials for Improving the Performance of Tunnel, Shaft, and Raise Boring Machines: *L. Ozdemir*, Colorado School of Mines, Golden, CO; *R. J. Evans*, Pittsburgh Mining Technology Center, Pittsburgh, PA; and *R. J. Miller* and *W. R. Sharp*, Colorado School of Mines, Golden, CO.

A serious handicap for TBM manufacturers, which has prevented them from designing an optimum cutting head and from being able to scale up to a larger diameter machine, is a general lack of understanding about cutter forces, cutter lacing patterns, and cutterhead shape and design in relation to geologic parameters. The DOE has funded a research contract with the Colorado School of Mines to design and fabricate a 1.83-m (6 ft) diameter experimental rotary cutter machine instrumented to measure and record cutter forces while operating either in the vertical, horizontal, or inclined position. The machine has been designed through a concentrated effort with all TBM manufacturers and contractors so that it will duplicate field boring conditions as closely as possible. It is anticipated that every critical aspect of TBM design and operation can be tested with this machine that has the potential to increase the efficiency and rate of boring machine extraction, eliminate costly overdesign, increase machine availability, and expand overall application of egress machines. To allow the measurements to be made of machine operation parameters and cutter forces, an extensive instrumentation program has been undertaken. Using commercially available sensors, the machine has been instrumented to measure thrust force, torque, penetration rate, and RPM during testing. Case studies are presented of test data and results which are correlated with field machine trials.

Laboratory Disc Cutting Studies in Medium and Hard Rocks: *J. Temporal, R. A. Snowdon*, and *M. P. O'Reilly*, Transport & Road Research Laboratory, Berkshire, England

The paper describes studies made at the Transport and Road Research Laboratory, UK, of the mechanical cutting characteristics of rocks with compressive strengths up to 340 MPa using disc cutters. These studies have been performed in both the single pass mode, where interactive breakout occurs between adjacent grooves on every pass of the tool, and the multiple pass mode, where several passes may be required to cause breakout. In addition, experiments to determine the effect on cutting performance of the hydraulic stiffness of tunneling machines are described. The results of these tests are analysed and discussed in the context of the design of full-face tunneling machines.

A Unified Rock Classification for Drilling and Boring: *L. Adler* and *G. V. Krishnan*, West Virginia University, Morgantown, WV

To drill rock safely and efficiently, it is essential to match the drill type to the in situ rock. A unified rock classification is developed to accomplish this. It also estimates the vital performance parameters of penetration rate, bit wear, and availability. The proposed method applies to access openings, wells, blastholes, and exploration. In all cases the rock is the major independent variable and drillability summarizes its jobrelated properties. The pertinent rock properties are strength, specific energy, abrasiveness, density, and mineralogy. Drillability is related by tests emphasizing hardness and visual examination. A five category classification is proposed ranging from very low strength to very high strength rock, based on a widely-used rock mechanics classification. All mechanisms are examined using multiple correlations; they are closely fitted into the classification. That not only defines their application, but provides the performance parameters, recommends bit type, and predicts the machine parameters of thrust, rotary speed, and flushing agent characteristics. The drillability classification is coordinated with blastability, diggability, and rippability to obtain a full spectrum of excavating possibilities.

IMPROVING CONTRACTING METHODS

2:30 PM — **Monroe**

Chairmen: E. J. Ruff, Thelen, Marrin, Johnson & Bridges, San Francisco, CA
D. de Benedictis, Thelen, Marrin, Johnson & Bridges, San Francisco, CA

Improving Contracting Methods—The Engineer's Viewpoint: *T. R. Kuesel*, Parsons, Brinckerhoff, Quade & Douglas, Inc., New York, NY

The designer's first contribution to improving contracting practices should be to prepare a set of contract documents that are relevant to the construction problems, as well as the design requirements. A program of Constructability Review and Claims Avoidance will go far toward establishing a climate of fair and equitable contract administration. For complex projects, particularly underground, a program of risk sharing should be built into the specifications and bid schedules to reduce excessive contingencies and attract competent bidders. For unusually difficult projects, a mediation-arbitration or disputes review board can provide a forum for equitable resolution of unanticipated problems.

Equitable Contracting and Risk-Sharing: *J. K. Lemley*, Morrison-Knudsen Co., Inc., Boise, ID

The human element in contracting arrangements in large measure dictates the success of contracting relationships. Contract documents can encourage or constrain the performance of individuals in carrying out professional responsibilities. Contractors are required to deal with the contract documents provided by the owner and his engineer for use in the contracting process. This perspective will be explored using two examples: 1) Seabrook Power Station Cooling Water Tunnels, and 2) New York City Water Tunnel #3. These two projects provide extreme examples on both sides of the performance picture. In addition, other examples of successful and unsuccessful contracting arrangement will be reviewed as they affect human and professional performance.

Improving Contracting Methods—The Owner's Viewpoint: *S. D. Guy*, US Bureau of Reclamation, Washington, DC

The work of the US National Committee on Tunneling Technology and some apparent results of the implementation of these recommendations or lack thereof is overviewed. Selected recommendations not being implemented are discussed as to the desirability and the possible impact of their implementation. Impediments to acceptance of the recommendations are identified and solutions proposed. The difference in the flexibility and attitudes and approaches of owners and the public and quasi-public and private individuals toward improving contracting methods are discussed. Particular emphasis is given to the fact that the onus to improve is on the owner because they usually develop the contractual language or at least have the final decision on its content.

The Lawyer's Role in Improving Contracting Practices in Underground Construction: *R. A. Rubin* and *L. A. Banick*, Postner & Rubin, New York, NY

To improve contracting practices, the lawyer should function as a prophylactic rather than as a sword. The lawyer can have a constructive role in disputes avoidance in both the drafting and the administration of contracts. He can effectively resolve disputes expeditiously before they escalate and positions harden.

TUESDAY, JUNE 14, AM

THE EXCAVATION AND SUPPORT OF VERTICAL AND INCLINED SHAFTS

9:00 AM — **Red Lacquer**

Chairmen: R. S. Hendricks, J. S. Redpath Corp., Tempe, AZ
G. A. Stafford, The Ralph M. Parsons Co., Pasadena, CA

Sinking the Silver Shaft: *B. A. McKinstry*, J. S. Redpath Corp., Tempe, AZ

This paper will describe the design and construction of the Silver Shaft at Hecla Mining Co.'s Lucky Friday mine. This 5.48-m (18-ft) diameter circular concrete lined shaft will have an ultimate depth of 2.34 km (7700 ft) and will be the deepest shaft outside of South Africa. Several North American shaft sinking records have been established during construction of the facility. The paper will deal with various aspects of the design of the basic facility as well as the selection and design of construction methods and equipment. The paper will describe actual performances achieved during shaft sinking and various associated construction operations.

Sinking a Freeze Shaft with Installation of a Water-Tight Flexible Lining: *K. Stoss* and *B. Braun*, Deilmann-Haniel GmbH, Dortmund, Germany

This paper will describe the sinking of a shaft having a finished diameter of 8.6868m (26 ft 3 in.) and a total depth of 1.128 km (3700 ft) with three (3) large double-

entry stations. The upper portion of the shaft was sunk through water bearing, unstable overburden to a depth of 217 km (712 ft). The owner required a lining system providing long-term stability and absolute water tightness even though mining activities take place in the immediate proximity of the shaft (no safety pillar). The system consists of a flexible outer lining and a flexible inner lining separated from each other by an asphalt layer. The paper will discuss the types of machinery and equipment used to perform the work giving important technical data. The sinking and lining operations of the shaft as well as the excavation and lining of the filling stations using the new Austrian tunneling method are described giving detailed performance rates.

Big Hole Drilling—State-of-the-Art: *M. D. Lackey*, Reynolds Electrical and Engineering Co., Inc., Las Vegas, NV

The Art of Big Hole Drilling has been in a continual state of evolution at the Nevada Test Site since the start of underground testing in 1961. Emplacement holes for nuclear devices are still being drilled by the rotary drilling process, but almost all the hardware and systems have undergone many changes during the intervening years. The current design of bits, cutters, and other big hole drilling hardware results from contributions of manufacturers and Test Site personnel. The dual string, air lift, reverse circulation system was developed at the Test Site; necessity was really the mother of this invention, which is worthy of consideration under almost any condition. Drill rigs for big hole drilling are usually adaptations of large oil well drill rigs with minor modifications required to handle the big bits and drilling assemblies. Steel remains the favorite shaft lining material, but a lot of thought is being given to concrete linings, especially precast concrete.

Drilled Shaft Construction at Crownpoint, New Mexico: *H. E. Hunter*, Conoco, Inc., Houston, TX

The Wyoming Minerals—Conoco Crownpoint Project Joint Venture is the first time a big hole drilling has been exclusively used to develop a privately financed mine design. Three shafts, one 3.05 m (ten ft) in diameter and two 1.8 m (six ft) in diameter, have been successfully drilled to depths of 683.7 m (2243 ft), 666.9 m (2188 ft), and 666.9 m (2188 ft), respectively, and lined with hydrostatic designed steel casing. The largest shaft is a development shaft to handle muck and water from enlargement and station excavation of the other two shafts. A reverse fluid air assist circulation system with potassium base mud was used during drilling. Deviation was monitored with wireline gyroscopic surveying instruments. The drilling operation was completed ahead of schedule and under budget.

GEOTECHNICAL DATA IN CONTRACT DOCUMENTS

9:30 AM **Monroe**

Chairman: A. W. Hatheway, University of Missouri, Rolla, MO

Improvements in Geotechnical Aspects for Corps of Engineers Contract Documents for Underground Construction: *A. W. Hatheway*, University of Missouri, Rolla, MO; *J. A. Albritton*, US Army Corps of Engineers, Omaha, NE; and *L. B. Underwood*, Consulting Engineering Geologists, Omaha, NE

The Missouri River Div. (MRD), US Army Corps of Engineers (COE) identified desirable and needed changes in exploration methods and geotechnical aspects of contracting for underground construction. For many years, Corps contracts have served as models for contract documentation by many agencies and private enterprise. Many standard features of present-day contracting methods were Corps innovations. As in the case of the underground construction industry, COE officials are well aware of the limitations recommendations of the three "Better Contracts" reports issued by the US National Academy of Sciences (NAS) through the US National Committee on Tunneling Technology (USNCTT). The authors and co-workers have determined that additional changes are warranted for underground construction contracting methods, changes that deal specifically with site geologic conditions, both known and reasonably suspected, and with their associated geotechnical impacts. The 1982 MRD report specifies the need for a number of improvements in the geotechnical aspects of contracting, improvements based on geological conditions.

Improvements in Exploration Programs and Presentation of Geotechnical Information: Program Management Approach, Milwaukee Water Pollution Abatement Program: *W. B. Thayer*, D'Appolonia Consulting Engineers, Inc., Milwaukee, WI and *J. H. Weinholz*, Milwaukee Metropolitan Sewerage District, Milwaukee, WI

The Milwaukee area has an extremely complex geologic environment. Glaciation has had a major impact. The rock surface ranges from outcroppings in the northern and western parts of the area to 76m (250 ft) below the surface at the mouth of the Milwaukee and Menomonee Rivers. Bedrock beneath the glacial mantle is a thick sequence of early to middle Paleozoic sedimentary rocks. To cope with the many complexities of this large public works project, a Program Management Office (PMO) concept has been employed. Within the PMO, a Geotechnical Engineering Group provided a continuous and unified approach to geotechnical engineering, providing full disclosure of all geotechnical information in the construction contract documents. A unique organization structure handled the multifaceted program. Several functions of the geotechnical group included providing geotechnical engineering to design and construction, developing and maintaining a program geotechnical data base, and participation on the Program Claims Resource team. In addition, this overall approach to geotechnical engineering will be compared to previously employed approaches of the MMSD and other public owned super projects.

Managing Subsurface Explorations for Sewer Tunnels in Rochester, New York: *J. W. Critchfield*, H & A of New York, Rochester, NY and *G. S. Brierley*, Stone & Webster Engineering Corp., Denver, CO

This case history of a subsurface exploration program was conducted for a system of sewer tunnels in up-state New York. The discussion focuses on a non-technical outline of how the exploration process was organized to efficiently produce a large body of geological and geotechnical data. A brief description of the project and geological setting is provided, the scope of the exploration program is summarized, the logistics of collecting, processing and reporting subsurface data is outlined, and recommendations for management of explorations applicable to any rock tunnel project are provided.

Truth, Judgement, Integrity, Responsibility, Conflict Resolution in Exploration and Heavy Construction: *P. J. Tarkoy*, Sherborn, MA

A great deal of money and dialog has been directed toward the adequacy of exploration for heavy construction projects, differing site conditions, and the adversary relationships which generally develop as a result of differences of opinion and responsibility become apparent. The solution requires strict and equal adherence to given principles by all parties involved, throughout the life of the project, from concept to construction completion. In a renewed context, the role of integrity, responsibility, truth, and judgement in exploration, engineering design, construction estimating, and project construction, will be examined and their impact on the industry defined. Detailed suggestions will be made to firmly establish and present to the bidder an unconditional set of anticipated geotechnical conditions. Similarly, an unequivocal establishment of encountered conditions that are agreeable to both owner and contractor will be presented. As anticipated and encountered conditions are firmly and accurately established, differences are easily defined. Methods of establishing economical effect of these differences will also be discussed.

SOFT GROUND TUNNELING

9:00 AM **Adams**

Chairman: T. G. McCusker, San Francisco, CA

Recent Advancements in Slurry Shield Tunneling: *Y. Kawarabata*, Okumura Corp., Abeno-ku, Osaka, Japan

The slurry shield tunneling method, developed to seek a most reliable alternative for tunneling in soft grounds under high water pressure, has proved quite successful and significant improvement has been made in Japan. At present, emphasis is being placed on the enhancement of its adaptability to various ground conditions and on its automatic driving. This paper presents the latest topics pertinent to the slurry shield system, including the following developments. The first is development of a small diameter (1,250 mm) slurry shield machine equipped with a crusher that is suitably designed for excavating bouldery ground. Secondly, development of a computerized slurry shield system adopted for the Pipe Jacking method and characterized by automatic tunneling operation and control from shield driving through backfill grouting.

New Developments in Bentonite Shield Tunneling: *C. Becker*, Wayss & Freytag AG, Frankfurt, Germany

This paper relates two unusual bentonite shield tunneling jobs: a very big shield in various grounds in Rome and a cost reducing cutting device by immerged jets in rolly ground. The Aurelia tunnel is a two track railway tunnel driven by means of a 10.64m O.D. shield through various grounds under the city of Rome. After 1050 m clay with an open front and dry mucking, the shield was transformed to a Hydroshield before entering waterbearing sands. The WF-Hydrojetshield is used in loose ground: simple oscillating slurry jets replace the expensive mechanical cutter head. The pressurized slurry acts as cutting, stabilizing, and transporting medium.

An Experience on the Use of Open Shield in Softground Shallow Tunneling: *R. M. Ocampo-Franco*, Comision de Vialidad y Transporte Urbano, Mexico City, Mexico

The line seven, as part of the development of the Subway Master Plan in Mexico City, will tunnel under different subsoil conditions of clay with high water content and low shear resistance located between 8 and 12m beneath the surface. Boulders in silty-sand and gravel to a 40m depth underlay this stratum. Economics, scheduled time of construction, and the obligated interconnection with existing lines one and two determined the construction of the tunnels to have an overburden of 1.0 to 2.2 times the diameter. In the north part of line seven there is a track of 251 m length that was decided to attack with an open shield of 9.14 m of diameter due to the characteristics of the subsoil, minimum section needed as well as a minimal overburden, of 10.41 m. The paper explains the construction procedure from the excavation stage to the reinforcement of the final lining obligated for the ground subsidence as a result of volumetric changes of a stratum of 4 m thick of clay overlying the crown of the shield.

Interaction of Design, Construction, and Owner on Small Diameter Tunnels: Northeast Side Relief Sewer System, Milwaukee Water Pollution Abatement Program: *A. J. Sobczak*, J. C. Zimmerman Engineering Corp., Greendale, WI and *P. J. Peters*, Milwaukee Metropolitan Sewerage District, Milwaukee, WI

The Northeast Side Relief Sewer System tunnel contracts (5), valued at $50 million are approximately 80% complete. The tunnels are all small diameter 2.3m (7.5 ft) in soft ground, mixed face and rock. Problems encountered and handled during construction included: use of filter fabric outside of lagging to minimize fine migration. Use of red oak lagging in areas of fluctuating water table. Alignment control problems were encountered in a section of jacked pipe. In addition, a .37 km (1200 ft) test section of smooth concrete segmental liner will be installed on one contract.

Geotechnical Aspects of the Mt. Baker Ridge Tunnel—Design: *H. W. Parker*, *R. A. Robinson*, and *S. R. Thompson*, Shannon & Wilson, Inc., Seattle, WA

The Mt. Baker Ridge Tunnel will be the nation's largest diameter soft ground tunnel when completed in 1986. The 19.2m (63 ft) inside diameter 0.4 km (1332 ft) long bore will carry five lanes of traffic through a ridge of glacially overridden fissured clay, silt, and sand uniquely supported by incrementally constructing 24 contiguous concrete filled drifts to form a flexible circular liner and then removing the soil core. Major geotechnical factors affecting the selection of design and construction methods include: the variable strengths of the fissured clays which have contributed to major Seattle slope failures, the tendency for long-term degradation of the clays in free water, isolated boulders, glacially induced increased horizontal stresses, a perched groundwater table in silty sands overlying the clays, and a soil cover ranging from over 30m (100 ft) to as little as 3m (10 ft). The paper also discusses the results of several geotechnical investigations over the last 17 years involving several phases of borings, excavation of an access shaft and three instrumented test adits, model tests, and finite element studies to assess ground response during construction of the main bore.

TUESDAY, JUNE 14, PM

DESIGN, CONSTRUCTION, AND SUPPORT OF LARGE PERMANENT UNDERGROUND OPENINGS

2:30 PM **Adams**

Chairmen: E. Hoek, Golder Associates, Vancouver, B.C., Canada
D. Willett, Acres America, Inc., Buffalo, NY

Some Geologic Factors in the Location, Design, and Construction of Large Underground Chambers in Rock: *A. S. Nieto*, University of Illinois, Urbana, IL

The paper discusses generic groups of geologic factors affecting the initial planning of exploration programs as well as the location, design, construction, and performance of large underground openings in rock. Although these generic groups actually interact to create geologic features that control strength, deformability, hydraulic conductivity, and stress state of rock masses, their discussion as separate groups is instructive. The paper will discuss the following main groups: lithology (as it determines properties of particular rock types like rock salt, shale, limestone, volcanics, and metamorphics), structure (as it affects discontinuities and their attitude), weathering (as it modifies properties of discontinuities and intact rock), recent geologic history (as it affects stress state), and groundwater. Illustrative examples are presented from the literature and from unpublished cases.

Evaluation of Design and Performance— Porter Square Transit Station Chamber Lining: *H. H. Einstein* and *A. S. Azzouz*, Massachusetts Institute of Technology, Cambridge, MA, and *A. F. McKown* and *D. E. Thompson*, Haley & Aldrich, Cambridge, MA

The Massachusetts Bay Transportation Authority excavated a major near-surface, hard rock chamber as part of the proposed Porter Square subway station in Cambridge, MA. The chamber is approximately 183 m (600 ft) long, 21 m (70 ft) wide, and 14 m (45 ft) high, and is supported by light steel sets embedded in a 38.1 cm (15 in.) thick shotcrete lining. The performance monitoring program used extensive construction control instrumentation, convergence measurements (made as part of an earlier UMTA grant), and field observations of construction procedures. Thus the validity of design assumptions and the adequacy of the design procedure could be assessed. In addition, a number of empirical design methods as well as predictions made by finite element analyses were compared with the engineer's design and with the actual performance.

Design and Construction of Minghu Power Cavern: *C. Y. Kao*, Taipower, Shuili, Taiwan, China, and *R. Y. Cheng* and *C. S. Hsieh*, Sinotech Engineering Consultants, Inc., Taipei, China

The mushroom-shaped Minghu power cavern located in central Taiwan is 21.2 m (W) by 40.5 m (H) by 127.2 m (L) and is designed to house four units of power generating-pumping equipment with a total capacity of 1,000 MW. This paper presents an introduction to the geological conditions, the rock tests, the design approach, the construction method and sequence, and the instrumentation provided in the roof arch to monitor the behavior of the surrounding rocks. The measured data from the embedded instruments will be compared with those obtained from theoretical analyses. Several technical problems encountered during the construction stage are covered and the solutions of the problems reached are also described therein.

Scheduling of Excavation for Underground Powerhouse: *L. J. Cousineau* and *A. Geoffrion*, James Bay Energy Corp., Deaconsfield, P.Q., Canada

This paper will treat the optimization of access, the division of the work into contracts, the sequences of excavation to meet the overall schedule, and the required interface milestones for each contract. Some points will be made on the rock shoulders for the permanent cranes, on the methods of excavation, and on the type of rock support required. A general comparison will also be made with Churchill Falls, Labrador, and Outardes 3, Quebec.

RECENT EUROPEAN EXPERIENCE

2:30 PM **Red Lacquer**

Chairman: H. E. Cronin, Underground Consultants Inc., Chagrin Falls, OH
A. A. Mathews, Federal Way, WA

Mechanical Heading of the Walgau-Headrace-Tunnel in Austria: *E. U. Schneider*, Fa. Ing. K. Jager, Batloggstrasse, Austria

With its length of 21 km and a diameter of 6.25 m the "Walgaustollen" is the largest pressure-tunnel ever built in Austria. After thorough studies owner and contractors decided to undertake the excavation with a full-face TBM. The vast variety of geological strata encountered in this part of the Austrian Alps and the amount of water enclosed proved to be a singular challenge for men and machinery. Severe faults required special treatment: drilling exploration and dewatering holes, grouting and pilot-heading in front of the TBM. Interruptions of several days or weeks in connection with flooding of the tunnel could not hinder accomplishment well ahead of schedule.

NATM Usage in Difficult Ground Conditions: *H. Distelmeier*, Bilfinger & Berger Bauaktiengesellschaft, Mannheim, Germany

The economy of the New Austrian Tunneling Method is based on the adaptability to various dimensions of cross sections. Parallel to the application in rocktunnels, the NATM has been used in soft ground for some years. The limits in use caused by the property of the subsoil can be partly extended with the help of auxiliary construction measures. Three examples of executions of construction, namely in Stuttgart, Munich and Bochum, will point out the technical and economical advantages of different auxiliary construction measures in connection with the NATM.

Modern Tunneling Technology In Deep German Coal Mines Under Difficult Ground Conditions: *D. F. C. Hudewentz*, Institut für Betriebsführung im Bergbau der Westfälischen Berggewerkschaftskasse, Bochum, Germany and *A. H. F. Lücker*, Gesteins und Tiefbau GmbH, Recklinghausen, Germany

Handling difficult ground conditions is a problem often encountered in deep German coal mines. Typical are zones of difficult ground caused by fissures or by friable shale or by geological faults with loose masses and water. In these zones there is always danger of overbreak and rockfall which threaten the face crew and the equipment. To keep off these dangers, special technologies have been developed. They are practiced prophylactic ly or parryingly. In the last years technologies have been intensified. The ratio of expenses and success is satisfactory as practical experience in several headings has shown.

Hydraulically Supported Faces in Coarse and Loose Soils: *L. Anheuser*, Wayss & Freytag AG, Frankfurt, Germany

Theoretical research, laboratory tests, and practical experience confirm the possibility of stabilizing even very coarse ground with high permeability by suitable slurries. Construction of the subway lot H 110 in Berlin by the Hydroshield method permitted checking the design assumptions for front support and surface subsidence under extremely mixed face conditions. The Hydrojet cutting system—excavation by immerged slurry jets—still reduces cutting wheel-induced soil perturbance in coarse stony strata. Proven types of dependable shield tail seals—necessary condition for atmospheric conditions inside the tunnel—are presented with an original facility for seal repair in waterbearing soil.

TECHNICAL AND ECONOMIC IMPORTANCE OF RAPID EXCAVATION IN THE MINING INDUSTRY

2:30 PM **Monroe**

Chairmen: B. A. Kennedy, Thyssen Mining Construction Co., Denver, CO
G. Matthes, North American Mining Consultants, Denver, CO

Evaluation of Alternative Shaft Sinking Methods for Nuclear Waste Repositories: *L. P. Gonano*, Golder Associates, Bellevue, WA and *S. Phillips*, The Cementation Co. of America, Tucson, AZ

A comparative evaluation of conventional and mechanized shaft sinking techniques is presented in the content of the particular geological and design constraints applicable to vertical circular shafts for high level nuclear waste deep geologic repositories. For each of the various methods, appropriate designs are developed, construction feasibility appraised, and the suitability of each method to the unprecedented design requirements assessed. The appraisal serves as a rational basis for the preliminary selection of the most suitable sinking techniques.

Technical and Economic Aspects of Rapid Shaft Construction with a V-Mole: *N. P. Hanke* and *R. B. Gabitzsch*, TMCI Construction, Inc., Lakewood, CO

During 1982, use of a V-Mole (vertical tunnel boring machine) has achieved record advances in the excavation of vertical shafts. The V-Mole, supplied by Wirth GmbH in Erkelenz, West Germany, has been used in West German coal mines since the early 1970s, mainly for the construction of internal shafts. In 1980 a machine was brought to the US to construct a series of ventilation shafts with depths of approximately 518- 625 km (1,700 to 2 050 ft). The excavation diameter was 7.01m (23 ft). These shafts are needed to develop coal mines for Jim Walter Resources, Inc. in Brookwood, AL. This paper briefly describes the V-Mole mechanized shaft excavation system, and then discusses the conditions and parameters required for the successful use of this method. These include ground conditions, shaft dimensions, and lining requirements. The advantages and disadvantages of the V-Mole method in comparison to other shaft construction methods are evaluated as are the possibilities for improvement of the V-Mole method.

New Boomheading Machines (Roadheaders) Technical & Economic Integration Into Mine Development and Production: *H. J. Handewith*, Boeing Services International Inc., Pleasant Hills, PA

Long used in mine development in England, Europe, and Russia, roadheaders are growing in size, features, productivity, and application. Beginning with the basics, this paper covers the economic and technical fit of the new roadheaders in both mine production and development. The author explains how to choose and integrate roadheaders into ongoing operations as another step in the inexorable march from labor to capital intensive mining. Innovations now on the drawing boards are covered, these are the challenge of the future.

Estimating Tunneling Costs Using an Interactive Computer Model: *W. R. Sharp*, Colorado School of Mines, Golden, CO, *W. E. Little*, Laramie Energy Technology Center, Laramie, WY, and *E. R. Kennedy*, Robbins Co., Kent, WA

The cost of mechanical tunneling requires the knowledge of many machine-rock parameters such as: rock type, machine power, penetration rate, cutter life, maintenance schedule, etc. Capital investment, labor requirements, and project scheduling will all play an important role in defining the economics of the overall project. Knowledge of the cost sensitivity of different project parameters will improve the overall success of any particular tunneling project if this information is incorporated into an effective management plan. Through the use of an interactive graphic computer program written for a microcomputer, one can quickly evaluate relative costs for a variety of parameters for either an existing project or for a proposed site. In addition to the cost aspects of a tunneling project, this paper will cover such items as the expected variations in tunnel advance rates due to scheduled and unscheduled delays.

WEDNESDAY, JUNE 15, AM

CONSTRUCTABILITY

9:00 AM **Red Lacquer**

Chairman: T. P. Smirnoff, Howard, Needles, Tammen & Bergendoff, Kansas City, MO

Design of Mount Baker Ridge Freeway Tunnel in Seattle: *E. B. Johnson*, *L. J. Holloway*, and *G. Kjerbol*, Howard, Needles, Tammen & Bergendoff, Bellevue, WA

The Mount Baker Ridge Tunnel is a major improvement of Interstate Route 90 in the state of Washington. The total length of planned underground construction is about 1000 m (3400 ft) of which 406 m (1332 ft) will be constructed by a stacked-drift tunneling method. Sized for vehicular traffic on two levels, the net interior diameter will be 19.2 m (63 ft) requiring an exterior diameter of about 24 m (80 ft). The material to be excavated is predominantly stiff clay, and this will be the largest-diameter tunnel ever attempted in soft soil. A construction contract for the stacked-drift tunnel was awarded in late 1982.

Excavation and Support of Gatineau Shaft: *R. E. Heuer*, Champaign, IL, *W. C. Cox*, Beaver Underground Structures, Dorval, P.Q., Canada; and *J. M. Loignon*, Jean-Luc Allary & Associates, Hull, P.Q., Canada

This paper describes design concepts, construction methods, and construction monitoring used for excavation and support of a 38.1m(125 ft) diameter, 21.4m (70 ft) deep shaft constructed at Gatineau, P.Q., in the stiff, highly sensitive Leda clay. The No. 3 gauge liner plate and W5 × 16 ring beams selected for support gave a very flexible lining for a shaft of this large diameter. Lining deformation had to be strictly limited in order to prevent clay liquefaction that could initiate lining buckling and catastrophic shaft collapse. Unusually restrictive methods of support installation ensured that the lining was constructed as a nearly perfect circle. Novel methods of construction monitoring ensured that unacceptable lining deformation did not occur.

Deep Underground Basing of Strategic Missiles, A 1983 Update: *L. Blake*, US Air Force, Norton Air Force Base, CA, and *E. S. Diamant* and *R. K. McFarland*, TRW, Inc.—SEBB, Redondo Beach, CA

A number of concepts for basing strategic missiles facilities deep underground have been developed within the defense industry. Recently, several contracts were let by the Air Force Ballistic Missile Organization to better develop system concepts for Deep Basing and Rapid Egress of Missiles from these facilities. A particular challenge of the Deep Basing Concept is the need for the excavation of egress tunnels or shaft from the deeply based facility to the ground surface in a rapid and reliable manner. This paper describes a conceptual MX-Deep Basing Facility, the technical issues associated with its design and construction, and potential means for achieving rapid egress from the facility.

Fort McHenry Tunnel—Value Engineering in Preliminary Design: *A. Gursoy*, Parsons, Brinckerhoff, Quade & Douglas, New York, NY

When completed, the eight-lane $1 billion Fort McHenry Tunnel, the final link of Interstate 95 in Maryland, will be the widest vehicular tunnel ever built by the trench

tube method. Careful coordination and planning were required to meet the tight and fast design and construction schedules. During the preliminary design, traditional design drawings were bypassed in favor of 25 preliminary design reports representing major work breakdown structures (tasks). For each task, alternative design solutions were examined and analyzed by means of trade-off studies on the basis of engineering, constructibility, and economic considerations, thus providing an overall conceptual value engineering approach for the entire project. So far, total value engineering proposed by the contractor for Contract II (largest contract of the project at $245 million) is less than 1.5% of the contract value. That is an important indication of the success of the design phase planning.

PIONEER MINING PROJECTS WITH PARTICULAR REFERENCE TO WATER-JET TECHNOLOGY

9:00 AM — **Adams**

Chairmen: D. A. Summers, University of Missouri, Rolla, MO
W. J. Kogelmann, AEC, State College, PA

Recent Developments in High-Pressure Water-Jet Assisted Cutting of Rock and Coal: *G. H. K. Schenck*, The Pennsylvania State University, University Park, PA

The use of high-pressure water jets—70 MPa (10 150 psi) and above—has the potential to provide the next major technical advance in cutting rock and coal. Water-jet drilling is already successful in hard sandstone. Cutting coal with standard equipment such as drum miners, shearers, and plows modified with water-jets shows a high probability of being the next major advance in underground coal mining. The most significant contribution of water jets to mining may be to increase the ability of boom-type continuous miners to cut rock 20% to 35% stronger than the maximum strength of rock that can now be economically cut by those machines. Most of the hardware problems have been solved and the products are on the job and working well in mines.

Water Jet Uses in Sandstone Excavation: *E. A. Zink, G. P. Zink, and J. E. Wolgamott*, Stoneage, Inc., Durango, CO, and *J. W. Robertson*, Atwood, CA

Equipment which will reliably produce high velocity water jets for use in rock excavation is now available. This report reviews cases where water jets were used to excavate low to medium strength sandstone in Colorado and Utah. Primarily, the paper discusses water jet assisted rotary drilling for blast and bolt holes in tunnels, shafts, and chambers. The subjects include drilling performance, effects on work environment, safety, and controlled blasting results. Information is also presented concerning trench excavation using water jets.

Development of a Water Jet Assisted Drag Bit Cutting Head for Coal Measure Rock: *L. Ozdemir*, Colorado School of Mines, Golden, CO and *R. J. Evans*, US Bureau of Mines, Pittsburgh, PA

This paper will present the results of an ongoing, federally funded research program at the Colorado School of Mines. The main objective of the program is to develop a water jet assisted drag bit cutting system for application to oil shale and coal mining. Water jets assist the mechanical cutter by providing reductions in cutting forces and bit wear, as well as dust generated from the cutting action. The concept of water jet assist involves the use of low pressure, low volume jets impinging directly in front of selected bits. Significant cutter force reductions and bit wear can be obtained through water jet assist. Presently, a large diameter laboratory drill rig is being fitted with a 71.16 cm (28 in.) diameter Dosco cutter head, equipped with point-attack cutter bits. Several of the bits on the cutter head will be equipped with water jets and tests run at various thrusts, rotational speeds, jet angles, pressures, and volumes to determine the degree of assistance provided by water jets. The system performance will be evaluated by analyzing the overall drilling parameters, as well as force measurements to be made on cutter bits fitted with water jets. This paper will also discuss the results of these tests and recommend the optimum design of a water jet drag bit cutting system.

Water Jet Coal Cutting: The Resource of an Old Technology: *W. E. Souder*, University of Pittsburgh, Pittsburgh, PA and *R. J. Evans*, US Bureau of Mines, Pittsburgh, PA

From time to time, major technological innovations arise that alter the time-honored ways of doing things. Such innovations can dramatically benefit society in terms of new products, increased outputs, reduced costs and general modernizations. However, the advent of these technologies is often resisted because of their uncertain potentials, and because they disrupt established routines and industry patterns. This paper reviews the case history of water jet cutting, and assesses its potential to become a major innovation within the next decade.

TUNNEL BORING PROJECTS FOR MINING AND OTHER NON-CIVIL APPLICATIONS

9:00 AM — **Monroe**

Chairmen: L. Home, Atlas Copco-Carva, Solon, OH
J. G. Taylor, Anglo American Corp. of S.A. Ltd., Welkom, South Africa

Incline/Decline Boring with Tunnel Boring Machines: *J. E. Brockway*, The Robbins Co., Kent, WA

As tunnel boring machine technology has expanded, so has its range of application. Tunneling machines (TBM s) are tackling tasks today that 15 years ago were considered "inappropriate." A case in point is incline/decline TBM boring. An incline or a decline bore presents peculiar machine design considerations that differentiate it from a horizontal bore. This paper reviews those design considerations as they apply to TBM s, backup, muck handling, and other tunneling sub-systems. In addition, several abbreviated case studies are presented. By the review of real life tunneling techniques as well as design considerations, the "appropriateness" of TBM incline/decline boring today becomes apparent.

Specific Problems Connected with the Application of Full-Face Tunneling Machines in German Coal Mines: *P. Loehr*, Thyssen Schachtbau GmbH, Ruhr, Germany

Full-face heading machines in German coal mines have been improved and their application widened in the past few years. The penetration to greater depths, extensive setting of supports, and difficult geological conditions impose further requirements on the equipment. Additional operations such as bolting in the face area to reinforce the supports should be integrated in the drivage work. The high efficiency of the present full-face heading machines imposes high requirements on the infrastructure of mine operation. Their sophisticated technique restricts application to a few large development projects with a heading length of at least 3000 m. Smaller machines should be developed to extend this well-proven method to drivage of in-seam headings. Initial consideration of this problem suggests that new machine designs are feasible. Joint efforts by contractors, mining companies, and manufacturers may successfully develop a new generation of full-face heading machines.

Tunnel Boring in South African Gold Mines: *A. C. Marlowe, I. Littleford*, and *M. Grun*, Anglo American Corp. of South Africa Ltd., Welkom, South Africa

An AAC owned Wirth 3.4m diameter tunnel boring machine completed a 1.15 km long tunnel at Free State Geduld Gold mine in South Africa in 1979. It was then extensively modified by Technical Development Services and The Wirth Co. In late 1981 the modified machine recommenced boring at the President Steyn Gold mine. It has provided new information about hard rock boring. The abrasive quartzites challenged the cutter manufacturer and the project team. Various types of cutters have been tested—at least two types are successful. This paper examines the problems faced, the solutions found, the results obtained, and the lessons learned. Detailed results in terms of performance, productivity, and unit costs will be presented for the present 2.7 km tunnel, which is due for completion in September 1983. The next generation of T.B.M. tunnel boring machines for use in inclines will also be discussed.

Mine Development with Heavy Roadheaders: *R. A. Pond*, Frontier-Kemper Constructors, Evansville, IN

Heavy (exceeding 31 641 (35 tons)) roadheaders have not seen much use in the United States, but are used extensively in Europe to excavate many types of underground openings in civil and mining applications. Early models of roadheaders were light and suitable only for utility excavation. Frontier-Kemper Constructors, Inc. is now using a 411 (45-ton) roadheader to excavate two mine slopes in Kentucky and a 70-ton roadheader to excavate a long decline at a new mine in Utah. Results to date indicate that heavy roadhead machines are an effective alternative to both conventional excavation and full-face boring machines in many cases, and, where circumstances are favorable, are a superior choice.

June 14-18, 1987
8th Rapid Excavation and Tunneling Conference
Sheridan, New Orleans, LA

WEDNESDAY, JUNE 15, PM

THE EXPLOITATION OF OIL SHALES, TAR SANDS, AND HEAVY OILS BY UNDERGROUND METHODS

2:30 PM **Monroe**

Chairmen: J. F. T. Agapito, J. F. T. Agapito & Associates, Inc., Grand Junction, CO
W. E. Spears, Jr., Sii Mining Equipment Cos., Houston, TX

Mechanical and Conventional Excavating Experience in Oil Shale Shafts and Tunnels: *R. B. Crookston* and *D. A. Weiss*, Tosco Corp., Aurora, CO; and *L. A. Weakly*, Exxon USA, Aurora, CO

This paper presents experience gained from using mechanical and conventional equipment for excavating shafts, raises, tunnels, and other openings in various Colorado and Utah oil shale mining properties

A New Technique for Mining Oil: *G. B. French*, Science Applications, Inc., Golden, CO and *D. E. Garrett*, Garrett Energy Research & Engineering, Ojai, CA

The amount of oil remaining unrecoverable in the United Sates oil fields totals about 48 m³ (300 B bbl). Heavy oil and tar sands reserves are about 5.5 m³ (35 B bbl). One method that could possibly recover a high percentage of these hydrocarbon resources is oil mining. Tunneling and underground drilling to enhance drainage, and surface strip mining are successful examples of such mining. It is proposed that another attractive procedure for shallow formations would be to strip mine a network of trenches through the deposit, and then drill horizontal holes for heating and draining. Economics of the method are presented.

Evaluation of Mechanical Excavation Systems for Oil Shale Mining: *R. J. Miller* and *L. Ozdemir*, Colorado School of Mines, Golden, CO and *R. H. Robinson*, Phillips Petroleum Co., Denver, CO

The paper summarizes an investigation into the applicability of mechanical excavation to oil shale mining, identifies available machine types that are best suited to various aspects of the mining operation, evaluates production and cost estimates to allow a benefit analysis, presents preliminary comments on the configuration of an IDEAL oil shale mining machine, and establishes the background information necessary for conceptualizing and evaluating new mining methods using mechanical excavation equipment. Conclusions are also presented as to the best currently available systems, as well as potential future systems.

An Underground Concept for Oil Field Development in Offshore Areas: *C. M. Tilley*, Littleton, CO

The possibility of drilling oil wells from underground locations is not a new concept. It has not been cost effective for the oil industry in the past and was therefore disregarded. Today's state of the art in tunneling and shaft sinking greatly improves the potential for this type of oil field development scheme. This report presents a plan for providing a series of drilling bases and the design of the drilling location. The design minimizes the amount of excavation needed to develop the oil field and maximizes the use of rapid excavation techniques.

GEOTECHNICAL EXPLORATION

2:30 PM **State Ballroom**

Chairman: D. Lachel, Lachel & Hansen, Inc., Golden, CO

Tunneling in Residual Soil and Rock: *K. P. Akins, Jr.*, Law Engineering Testing Co., Columbia, SC and *L. W. Abramson*, Law/Geoconsult International, Inc., Marietta, GA

The authors have accumulated published data on residual soil and rock tunnels in the US and have compared it to their tunneling experience in the Atlanta area. Two 6 m (20 ft) diameter shield driven, compressed air tunnels were constructed for the Metropolitan Atlanta Rapid Transit Authority (MARTA) connecting the Peachtree Center Station with the Five Points Station. Because of the historic high-rise structures above the tunnels and the variety of subsurface conditions, the ground was comprehensively monitored and observed. The data obtained is compared to other published data from residual soil and rock tunnels. Conclusions are drawn regarding residual soil and rock ground response due to tunneling.

Geotechnical Exploration for the Proposed Crosstown Transport Facility, San Francisco, California: *J. M. Gonzalez* and *T. N. Dunne*, Geotechnical Consultants, Inc., San Francisco, CA

This paper presents the case history of a comprehensive geotechnical investigation for the Crosstown Transport Facility, a 10.9 km (35,700 ft) long, 3.2m (10.5 ft) diameter pressure tunnel proposed for construction in San Francisco, CA. The proposed tunnel would be part of the City and County of San Francisco's Clean Water Program, and its purpose would be to convey stormwater and sewage from the east side of the City to the Pacific Ocean. Tunneling conditions were defined by surface geologic mapping, 94 exploratory borings, surface and borehole geophysics, aquifer testing, Goodman Jack testing, pressuremeter testing, and laboratory testing. Through the use of advanced coring techniques and an innovative drilling fluid system, core recovery averaged over 99% in the sheared and fractured rock of the Franciscan Formation. As a result, over 1.4 km (4700 linear ft) of rock core was recovered and is available for examination.

In Situ Stress Measurement in a Jointed Basalt: The Suitability of Five Overcoring Techniques: *E. C. Gregory, T. A. Rundle, W. M. McCabe*, and *K. Kim*, Rockwell Hanford Operations, Richland, WA

Overcoring tests were conducted at the Near-Surface Test Facility (NSTF) using the US Bureau of Mines borehole deformation gage, the CSIRO hollow inclusion stress cell, the cast epoxy inclusion, the Lulea triaxial strain cell, and the CSIR doorstopper gage to assess the suitability of each technique for in situ stress determination in a closely jointed basalt. The effort supports the Basalt Waste Isolation Project that is studying the feasibility of locating a nuclear waste repository in basalt. Testing at the NSTF provided information for evaluating overcoring techniques so that one or more can be selected to obtain in situ stress data at the reference repository horizon. Even though some problems were experienced, the borehole deformation gage and doorstopper proved the most successful.

MBTA Red Line Extension Northwest: Influence of Geology on Alignment and Grade: *F. M. Keville*, Massachusetts Bay Transportation Authority, Boston, MA and *H. Sutcliffe*, Bechtel Civil & Minerals, Inc., San Francisco, CA

The paper describes the impact of the geotechnical exploration program on the line and grade of the tunnels and the shaft configuration on the Red Line Extension NW in Cambridge and Somerville, MA, and comments on several aspects of the implementation of the project.

Current Methods of Objective Ground Assessment for Underground Construction: *G. E. Rawlings*, Golder Associates, Vancouver, B.C., Canada

Geotechnical investigations for underground projects are subject to a variety of constraints, including accessibility, geological complexity, thickness of overburden and finance. As a result, the extent of geological data available for route selection and assessment of underground design and construction problems may vary between wide limits. The data collected, the degree to which it is representative, and the confidence with which problems can be anticipated should be reflected in the type of contract set up. Investigations can be focussed to make suitable overall ground assessments for feasibility level studies. Subsequent investigations can then be objectively directed toward obtaining data on specific geotechnical problems or aspects that impact tunnel, cavern, and shaft design and construction. The extent of investigations at the preliminary and design engineering stages must be closely related to the geotechnical surveillance and control during excavation. Fixed-price contracts necessitate a secure geotechnical data base prior to bidding, and the provision of that to the tenderers. By contrast, design-as-you-go contracts minimize the geotechnical information needed before construction, yet require immediate assessment of the excavated ground to determine support requirements and payment category.

MATERIALS HANDLING

2:30 PM **Red Lacquer**

Chairmen: G. Miner, Phoenix, AZ
G. Wilhelm, Grand Junction, CO

Rail vs. Rubber Tired Handling—A Comparison from Two Projects: *T. Skodack*, Atlas Copco, Golden, CO

This presentation will compare actual work site results for the loading and transport of shot rock for two major tunneling projects in North America. SCARMAR (the

Canadian subsidiary of S & M Construction) is operating a *rail bound* Hagglund continuous gathering arm loader in combination with a Hagglund nine car shuttle/train system at the West End of Table Mountain on the B.C. Railway project near Tumbler Ridge, Canada. Al Johnson Construction is operating a Hagglund rubber tired continuous gathering arm loader in combination with haul trucks at the Rocky Mountain Pump Storage Project near Rome, GA. This paper will compare 1) tunnel and ground conditions, 2) the total work cycle as it relates to mucking and haulage 3) efficiencies and related problems with the two systems 4) mucking and haulage rates 5) operating costs, and 6) recommendations for future large tunnel excavations.

Loveridge Coarse Coal Slurry System—An Update: *D. W. Alexander* and *R. L. Shaw*, Consolidation Coal Co., Pittsburgh, PA

Consolidation Coal Co.'s Loveridge mine operates the only coarse coal hoisting and overland slurry transport system in North America. The system has been in operation since April 1980 and according to current haulage levels will have handled over two million tons by this conference. Original performance goals have been exceeded. The systems and their application to rapid excavation and tunneling haulage needs will be discussed.

A Helical Inducer Hydrotransport System for Tunneling and Boring Operations: *M. Burnett, J. C. Roberge,* and *L. S. Rubin*, Foster-Miller, Inc., Waltham, MA

A self regulating inducer has been developed and tested for dry injection of coarse to fine solids into a hydraulic pipeline. The centrifugal pumping device has also been modified and tested for use as a boost pump in medium and long distance pipeline haulage systems. The helical inducer has been operated as an integral component of a slurry injection vehicle. This compact, low profile vehicle includes crushing and screening components, solids feeding components, a track drive system for mobility, and is run by a single operator. The helical injector and boost pump which operate without speed and flow controls, allow for practical hydraulic transport of excavated materials.

Conveyor Conversion Cuts Costs: *D. G. Rasmussen*, Dravo Engineers, Inc., Denver, CO

With low commodity prices and continuing high operating costs, the mining industry must revise planning and operating to take advantage of every tool available. Conveyors operated within open pits are such a tool. Dravo engineers have designed conveyor systems into pits as prime movers in unique situations. Three cases are presented with economic comparisons made to conventional truck haulage. Increasing energy and labor costs tend to make conversion of prime haulage from trucks to conveyors. Long term pit planning and scheduling reduce the effects of conveyor inflexibility.

Technical Review of Mine Development: *L. P. Gignac*, Corp. Falconbridge Copper, Chapais, P.Q., Canada and *D. Tolgyesi*, Northgate-Patino, Chibougamau, P.Q., Canada

Mine development has evolved in the past 15 years from a human-paced system using hand-held drills and track-bound equipment to a mechanized system using specialized equipment for each component of the development cycle. In most Canadian hard-rock mines, face advance is achieved by the following sequential activities: drilling, explosive loading, mucking, and ground support. The state-of-the-art for each work element is reviewed and methods for performance estimates proposed. The entire development system and its production capabilities are considered based on equipment reliabilities, spare units, haulage distances, and muck bay spacing. The effect of the number of working faces on the system's performance will also be analyzed.

DRILLING, BLASTING, AND SUPPORT TECHNIQUES FOR RAPIDLY ADVANCING TUNNELS

2:00 PM **Adams**

Chairmen: W. Hustrulid, Colorado School of Mines, Golden, CO
L. Ottosson, Atlas Copco MCT AB, Stockholm, Sweden

Tunnel Excavation In Alaska Using High Speed Equipment: *A. G. Provust* and *M. S. Ness*, Harrison Western Corp., Denver, CO

High speed drilling, mucking, and hauling equipment was used in driving approximately 2.16 km (7100 ft) of tower power tunnel in quartz diorite for the Tyee Lake Hydroelectric Project near Wrangell, AK. The 91 m (36 in.) gauge rail mounted equipment included a Tamrock 2-boom electric/hydraulic drill jumbo, a Hagglund BHR mucker, and 3 Hagglund 115C shuttle cars. Several other innovative techniques allowed maximum advance rates of up to 17.5 m/day (57 ft/day) in the 3 m (10 ft) horseshoe section. Average tunnel advance was approximately 11 m/day (35.4 ft/day). The primary difficulties preventing full utilization of the equipment potential were the operators' learning curve, the need for complete retraining of all personnel in the new methods, and minor sections of bad ground.

Tunneling at Forest Glen Station, Washington, DC Metro: *W. W. Roberts*, Kiewit Construction Co., Omaha, NE

Key elements to the successful excavation and support of the Forest Glen Station and Tunnels for the Washington Area Metropolitan Transit Authority are discussed. Excavations encompassed a twin-vault station, 2 339 km (7,675 ft) of conventional drill and shoot rock tunnel, and .81 km (2,660 ft) of mixed faced tunnel. The use of dewatering, boom type continuous miner, and shotcrete in the mixed faced tunnel along with hydraulic drills, bolts, and shotcrete in the rock tunnels and station proved to be effective methods.

World Record Tunneling Project at Randfontein Estates Gold Mine: *L. S. Halasz*, Western Areas Gold Mining Co. Ltd., Westonaria, Transvaal, South Africa

This paper describes the techniques implemented at Randfontein Estates to develop twin-haulages at 'high speed'. The operation culminated in the world record advance for twin-end multiblast cyclic development in hard abrasive quartzites. A major expansion project was planned for the mine with the sinking of a third twin-shaft system (to be known as Cooke No. 3) to raise the level of ore production from 3.5 Mt to 5 Mt per annum. The proposed shaft system was redesigned as a single 9 m partition wall shaft, reducing the planned shaft sinking period by 12 months and saving an estimated R 250 000 (US $330 000) in sinking costs. The advancement of the Cooke No. 3 Shaft sinking and development programme necessitated a rapid excavation schedule for two interconnecting twin-haulages from the existing Cooke No. 2 twin shaft complex to provide a second means of egress. An early holing between the two shafts would provide significant financial and technical benefits. Pre-development and equipping of shaft pillar excavations would enable a rapid shaft production build up and blocking out of at least one year's ore-reserves.

Improvements on Blasting Technique for Headrace Tunnels: *Y. Kanoh* and *M. Ohtsuka*, Sato Kogyo Co., Ltd., Tokyo, Japan

In Japanese tunneling history, it has commonly been accepted that the deep-round driving is difficult due to the complicated geological condition. Therefore, the maximum past record has been less than 3m per round. A new record of advance was established in the 44m² headrace tunnel of Imaichi Water Power Station Project with an advance of 234.5m in a month by drilling 3.9m deep blast holes. The geology of the headrace tunnel composed of proxine andecite (ie. 460-1770 kg/cm², VP 3.1-4.3 km/sec) which had several clay seams and open cracks and was moderately weathered. An automatic shotcrete machine was used for shotcreting. Rock support was specified according to the NATM with each different rock type. The contractor achieved a remarkable tunneling advance not earlier experienced in Japan.

—NOTES—

APPENDIX B

DATA APPLICATIONS

As noted previously, each test with the rotary cutter generates a very large amount of data involving all pertinent parameters associated with system operation and performance.

Following is a summary of the areas in which tests on the rotary cutting machine can provide valuable information toward improving the understanding and performance of mechanical excavation systems.

Machine Parameters	- thrust, torque, steering power, vibration
Cutter Data	- forces, peak loads, life, heat configuration
Cutterhead Design	- spacing, shape, gage, shielding
Muck Handling	- up hole, down hole, horizontal, through shield, around shield, shield standoff, regrinding
Loose or Broken Ground	- effects on all of above considerations including stability
Performance Prediction	- in generic rock types, specific tunnel sites, loose or broken ground
Performance Improvement	- machine design, operating parameters, rock stabilization, rock fracture enhancement.

In addition to the above listed benefits, the rotary cutting machine can also accommodate the testing and evaluation of novel rock cutting techniques, such as water jets, tround drilling system etc.

Mechanical and Performance Parameters which can be monitored by the CSM-USBM Rotary Cutting Machine

(June 13th PM - Paper 2)